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EFFECTS OF WING AND TAIL LOCATION ON THE AERODYNAMIC CHARACTERISTICS OF AN AIRPLANE FOR MACH NUMBERS FROM 0.25 TO 4.63

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SUMMARY

Experimental investigations have been conducted to determine the effect of wing vertical position and horizontal-tail vertical and axial position on the static aerodynamic characteristics of a wing-body horizontal-tail configuration. The configurations investigated included the wing in a high, mid, or low position on the body with the horizontal tail in each of these vertical positions as well as in three axial positions. The closest position of the horizontal tail to the wing essentially provided an all-wing configuration. In addition, tests were made for the three wing positions with the horizontal tail removed. The tests were made in three different wind tunnels to provide data for a Mach number range from 0.25 to 4.63. The purpose of the investigation was to illustrate the strong effects of interference flow fields as a function of geometry and flight regime. An analysis of the results indicate some arrangements that might lead to aerodynamic problems and others in which the interference flow fields might be favorably exploited. The results suggest that a coplanar concept with a translating horizontal tail could potentially minimize the aerodynamic changes with Mach number and provide more optimum performance over the Mach number range.

INTRODUCTION

Among the problems associated with airplane design are the aerodynamic phenomena resulting from variations in Mach number and vehicle attitude. These phenomena are manifested as significant changes in lift, drag, stability, and control effectiveness as speed, angle of attack, and angle of sideslip are varied. These changes, which may become critical for airplanes intended to operate over a large speed range, result from compressibility effects and flow field interference effects. The shaping of an airplane, as well as the location of the components, has a strong effect on the aerodynamic behavior. In particular, the flow field effects between wings and tails play an important role. As part of a continuing study to determine the aerodynamic characteristics of airplane configurations, the present paper presents some results from investigations of a wing, body, horizontal tail model in which the wing was tested in high, mid, and low positions and with a horizontal tail also in a high, mid, and low position for each of three axial positions behind the wing. The closest position of the horizontal tail to the wing essentially provided an all-wing configuration for the coplanar arrangements. The resulting matrix of 27 wing-tail arrangements is useful in illustrating the interference flow field effects and could be used as a data base for correlation with various analytical techniques. Test results were obtained for the body with mid wing and tail positions at transonic and supersonic speeds (ref. 1); for the high- and low-wing-body-tail configurations at supersonic speeds (ref. 2); and at $M = 0.25$ for various tail positions with the mid-wing configuration with and without flaps (ref. 3).

Results from some other studies of wing-tail geometric effects may be found in references 4 to 12 for low speeds; references 13 to 17 for high subsonic speeds; references 18 to 19 for transonic speeds; and references 20 to 26 for supersonic speeds.

SYMBOLS

$C_{D,o}$	drag coefficient at zero lift
C_L	lift coefficient
C_m	pitching moment coefficient
C_{L_α}	lift curve slope, per degree
$\frac{\partial C_m}{\partial C_L}$	longitudinal stability parameter
C_{l_β}	effective dihedral parameter
C_{n_β}	directional stability parameter
C_{Y_β}	side force parameter
$\frac{\partial C_m}{\partial \delta}$	pitch control effectiveness
$\frac{L}{D}$	lift-to-drag ratio
$\left(\frac{L}{D}\right)_{max}$	maximum value of lift-to-drag ratio
$\frac{\partial \varepsilon}{\partial \alpha}$	variation of effective downwash angle at tail with angle of attack
α	angle of attack, degrees
δ	pitch control deflection angle, degrees
M	Mach number
$\frac{q}{q_\infty}$	ratio of local dynamic pressure to freestream dynamic pressure
L	lower surface (compression) flow field
U	upper surface (expansion) flow field
W	wing
B	body
T	horizontal tail

MODEL

Details of the model are shown in figure 1. The body was composed of a 3.5-fineness-ratio ogive nose with a cylindrical afterbody. The wing was trapezoidal in planform with a 67-degree swept leading edge and a 45-percent swept trailing edge. The wing section was slab shaped with a leading-edge wedge of 18 degrees (normal to the sweep angle) and a blunt trailing edge. The thickness ratio in the streamwise direction was 0.0366. Provision was made to locate the wing in the mid position or in either a high or a low position ($\pm$2.54 cm) from the mid position. The horizontal tail also had a trapezoidal planform but with a leading-edge sweep of 45 degrees (same as the trailing-edge sweep of the wing) and a thickness ratio of 0.0342 in the streamwise direction. The tail section was hexagonal with leading and trailing wedge angles of 10 degrees (normal to the respective sweep). The horizontal tail could be placed in the same vertical planes as those for the wing positions. In addition, the tail could be located longitudinally in three positions such that it was either adjacent to the wing (essentially an all-wing configuration), 7.62 cm behind the wing, or 15.24 cm behind the wing. Any combination of these wing and tail positions could be obtained. Two of the combinations are shown in figure 2. The horizontal tail was equipped with a 30-percent chord plain elevator that could be deflected $\pm$10 degrees.

DISCUSSION

Mach Number Effects

The typical manner in which some fundamental aerodynamic characteristics are affected by Mach number is illustrated in figure 3. Trends generally associated with compressibility effects include the C_{L_α} increase at subsonic speeds followed by a decrease at supersonic speeds, and the familiar transonic rise in $C_{D,o}$. A characteristic increase in longitudinal stability is evident through the transonic range both with and without a horizontal tail. One of the main contributing factors to this increase is a rearward center of pressure shift for airfoils as shock flow eliminates the forward upper surface negative pressure peak and the lift increases over the rearward portion of the airfoil. Other contributing factors include the carry-over lift from the wing to the body which, above $M = 1$, is all confined to the afterbody. The changes in longitudinal stability are generally large enough so that a conventional airplane configuration may become statically stable at supersonic speeds even without a horizontal tail.

Another aerodynamic change observed is the downwash variation with M for aft-tail airplanes. The observed characteristic is a gradual reduction in the effective downwash at the tail with increasing M and, often, the appearance of an upwash at supersonic speeds. The loss in downwash occurs primarily because the major portion of the downwash is generated by the wing tip vortex which, at supersonic speeds, is confined to the tip Mach cones and progressively begins to effect less of the tail. The appearance of upwash may occur from crossflow around the body as angle of attack is increased. As a result of this particular characteristic, the horizontal tail, which is sized to account for the downwash at subsonic speeds, becomes increasingly effective and contributes to the increased longitudinal stability in the transonic range. The primary problem associated with the increased longitudinal stability is the increased control power required to provide for trimming which, in turn, reduces the ability to maneuver. In addition, a lack of control power generally occurs with increasing M, also. The rapid decrease in pitch effectiveness of the conventional elevator control results primarily from shock-induced separation near the control.

For an all-moving tail control, a decrease in effectiveness may occur due to a decrease in tail lift curve slope.

One other significant characteristic of supersonic aerodynamics that should be noted is the ratio of local dynamic pressure to freestream dynamic pressure as a function of M for a lifting airfoil surface. In the upper surface flow field (expansion) the local q is substantially reduced whereas the lower surface flow field (compression) shows a significant increase in local q. Not only do these q changes affect the lifting surface itself, but also the characteristics of any other part of a vehicle located in the induced flow fields. The effectiveness of an aft tail, for example, could be seriously impaired if located in the upper surface flow field or considerably enhanced if located in the lower surface flow field.

Longitudinal Aerodynamic Characteristics

A summary of longitudinal parameters as a function of Mach number is shown in figure 4 for the centerline wing-tail configuration with various horizontal tail configurations. The longitudinal stability increase for the aft-tail arrangement is substantial, amounting to about a 25 percent increase in the static margin. The static margin progressively decreases at supersonic speeds as the tail is moved forward and, for this coplanar centerline arrangement, the tail contribution to the static stability appears to be reasonably linear over the M range.

The variation of C_{L_α} with M is typical for conventional configurations. Axial location of the horizontal tail has no measurable effect on the lift curve slope although the addition of the tail provides a 20 percent increase in C_{L_α} over that for the wing-body.

An interesting effect of the tail on the drag characteristics does occur. Although the addition of the tail in either the mid- or aft-axial positions causes an increase in $C_{D,o}$, the forward tail position results in $C_{D,o}$ values slightly less than those for the tail-off case. This drag reduction occurs since the forward tail is immediately aft of the wing and results in a decrease in wing trailing-edge drag as well as tail leading-edge drag. This reduction in drag coupled with the increased lift results in the forward coplanar tail configuration having the highest values of maximum L/D.

<u>Tail length effects</u>.- Typical effects of tail length are shown in figure 5 for the centerline wing and tail at $M = 1.70$. As should be expected, the longitudinal stability progressively increases as the tail is moved rearward. The effect on lift-curve slope is slight but the reduction in drag and increase in L/D with the forward tail is evident.

Effects of tail length on the longitudinal stability near $\alpha = 0°$ are shown as a function of Mach number in figure 6 for various arrangements of high and low wing and tail positions. For coplanar arrangements (high-high and low-low), the stability level varies uniformly with tail length and Mach number, progressively increasing as the tail moves rearward and progressively decreasing as M increases, indicative of an essentially linear and symmetric flow field. However, for the nonplanar arrangements (high-low and low-high), the stability variation is somewhat erratic both as a function of Mach number and of tail length indicative of a nonlinear, asymmetric flow field induced at the tail. To understand variations of this type or to attempt analytical predictions of such variations would require an accurate modeling of the wing flow field and a means for determining the integrated effect of the flow field over the tail for various locations of the tail within that flow field. There is little margin for error in attempting analytical solutions since the effects are significant. For the more forward tail locations, for example, the effect of changing from a coplanar to a nonplanar arrangement can make a difference between stability or instability over a rather large Mach number range.

Wing height effects.- The effects of wing height on the longitudinal stability are shown in figure 7 for the mid-tail length with both the high and low tails at $M = 1.70$ and 4.63. Reasonably linear variations of C_m with C_L occur for each coplanar configuration. Some nonlinearities occur for nonplanar arrangements, however. The results at $M = 1.70$ indicate a large nonlinear variation for the low wing, high tail configuration in the mid C_L range where the tail passes through the viscous wake from the wing. A much more linear variation occurs for the low wing, low tail configuration since the tail does not pass through the wake. Viscous wake effects tend to disappear as Mach number is increased and the local dynamic pressure fields become predominant. These pressure field effects are evident at $M = 4.63$. For the low wing, high tail, for example, the reduced dynamic pressure from the expansion side of the wing probably accounts for the initial reduction in stability. As the angle of attack increases, the tail moves out of the wing flow field and the stability rapidly increases. For the high wing, low tail arrangement at $M = 4.63$, the increase in stability with increasing angle of attack is even more pronounced as the tail tends to move into a region of increased local dynamic pressure generated beneath the wing.

The effects of wing height with the tail off are shown in figure 8. The high wing provides a slightly lower lift-curve slope, probably because the high wing is more affected by the body flow field. The high wing does provide a more stabilizing increment of C_m with increasing C_L, however, probably because of a greater carry-over lift increment from the wing to the afterbody.

Tail height effects.- The effects of tail height on the longitudinal stability for the mid tail position (fig. 9) are again a reflection of the relative locations of the wing and the tail and, hence, lead to the same observations as those found for wing height effects. That is, the coplanar arrangements are all found to be essentially linear whereas the nonplanar arrangements indicate different types of variations depending upon the interference flow fields that might be expected between the wing and the tail.

Tail effectiveness.- The pitch-control effectiveness of the trailing-edge elevator is shown in figures 10 and 11 for the high and low wings, respectively, for both the high and low tail at the mid tail length position. The ± 10 degree deflections generally reflect the same kind of stability variations as the 0 degree deflection and positive control effectiveness is maintained. There is evidence of the dynamic pressure change at $M = 4.63$, however, in that a measurable increase in control effectiveness occurs with increasing C_L (or α) particularly for the low tail which is more likely to be favorably influenced by the wing flow field and less likely to be influenced by the body flow field.

Relative planar effects.- A summary of the longitudinal stability and control characteristics for the mid-tail length at $M = 1.70$ and 4.63 is shown in figure 12 for coplanar configurations and in figure 13 for nonplanar configurations. When presented in this form, it can more easily be seen that the coplanar arrangements (fig. 12) are more desirable from the standpoint of linearity and for satisfactory static stability and control. The nonplanar arrangements, with the exception of the high wing, low tail at $M = 1.70$, indicate some undesirable nonlinear aerodynamics (fig. 13). The high wing, low tail configuration at M = 1.70, as discussed previously, is one in which the tail remains clear of the wing viscous wake and the local dynamic pressure changes in the wing flow field have not yet developed.

Lateral Aerodynamic Characteristics

The static lateral stability characteristics as a function of α with the tail off are presented in figure 14 for the high and low wing positions at M = 1.70 and 4.63. The characteristics are somewhat different between the two Mach number extremes, the lower Mach number results being dictated more by the viscous wake effects (induced upwash and sidewash) and the high Mach number results reflecting the local dynamic pressure changes in the flow field of the wing. The primary differences are in the effective dihedral and in the directional stability. At M = 1.70, the effective dihedral for the high wing levels off with increasing α probably due to wing stall for the leading wing panel in sideslip. Such a stall does not occur at the higher Mach number. The directional stability at M = 1.70 is somewhat erratic and results from a combination of drag differences between the leading- and trailing-wing panels and from the viscous wake induced sidewash effects over the afterbody. At M = 4.63, the noticeable increase in directional stability for the high wing probably results from an increase in local dynamic pressure induced over the windward side of the afterbody. Note that, for this case, the wing body became directionally stable at the highest angle of attack. In addition, the effective dihedral variation with remains reasonably linear since wing panel stall is not likely to occur at this Mach number.

Translating Tail Concept

The possibility of a translating tail concept utilizing desirable tail locations for low and high speeds is illustrated with the centerline wing-tail configuration in figures 15 to 17. The stability, control, and L/D characteristics are shown in figure 15 for the aft tail at M = 0.50 and the forward tail at M = 4.63, arrangements that are presumed to be the most desirable for these speeds. An artist sketch of such a variable tail length configuration is shown in figure 16 where the tail is in the most aft position for low speed flight and is translated forward to become adjacent to the wing for high speed flight. The aerodynamic characteristics attainable with a translatable tail are further illustrated in figure 17. Varying the tail from the aft position at low speed to the forward position at high speed reduces the stability variation with Mach number considerably; essentially eliminates the transonic drag rise; and increases the supersonic L/D. Similar results would be expected for either the high or the low coplanar configurations. Although the design considerations for a translating tail are challenging, the aerodynamic advantages are worthy of consideration. Other possible aerodynamic advantages are an effective reduction in wing aspect ratio and in wing loading--both of which could enhance supersonic performance.

CONCLUDING REMARKS

A review has been presented of the results of several experimental investigations of a body-wing-horizontal tail configuration at Mach numbers from 0.50 to 4.63. The configuration was tested with the wing and the tail in high, mid, and low vertical locations for three different tail lengths as well as with the tail removed. With the tail in the most forward location, the configuration represented essentially an all-wing design. A matrix of 27 wing-tail arrangements were tested for the purpose of demonstrating the effects of interference flow fields on the aerodynamic characteristics over an angle of attack and Mach number range. In general, the results indicated that, for lower Mach numbers, the viscous flow field effects are predominant whereas at high Mach numbers, the local dynamic pressure changes in the wing flow field dominate. The varying nature of the aerodynamic characteristics for the various configurations presents a challenge to the development of accurate predictive techniques.

Generally, the coplanar arrangements demonstrate more favorable characteristics than the nonplanar arrangements. The results suggest that a coplanar concept with a tail that could be translated in flight from an aft position to a position adjacent to the wing might exploit the flow fields in such a way as to minimize the aerodynamic changes and provide more optimum performance over the Mach number range.

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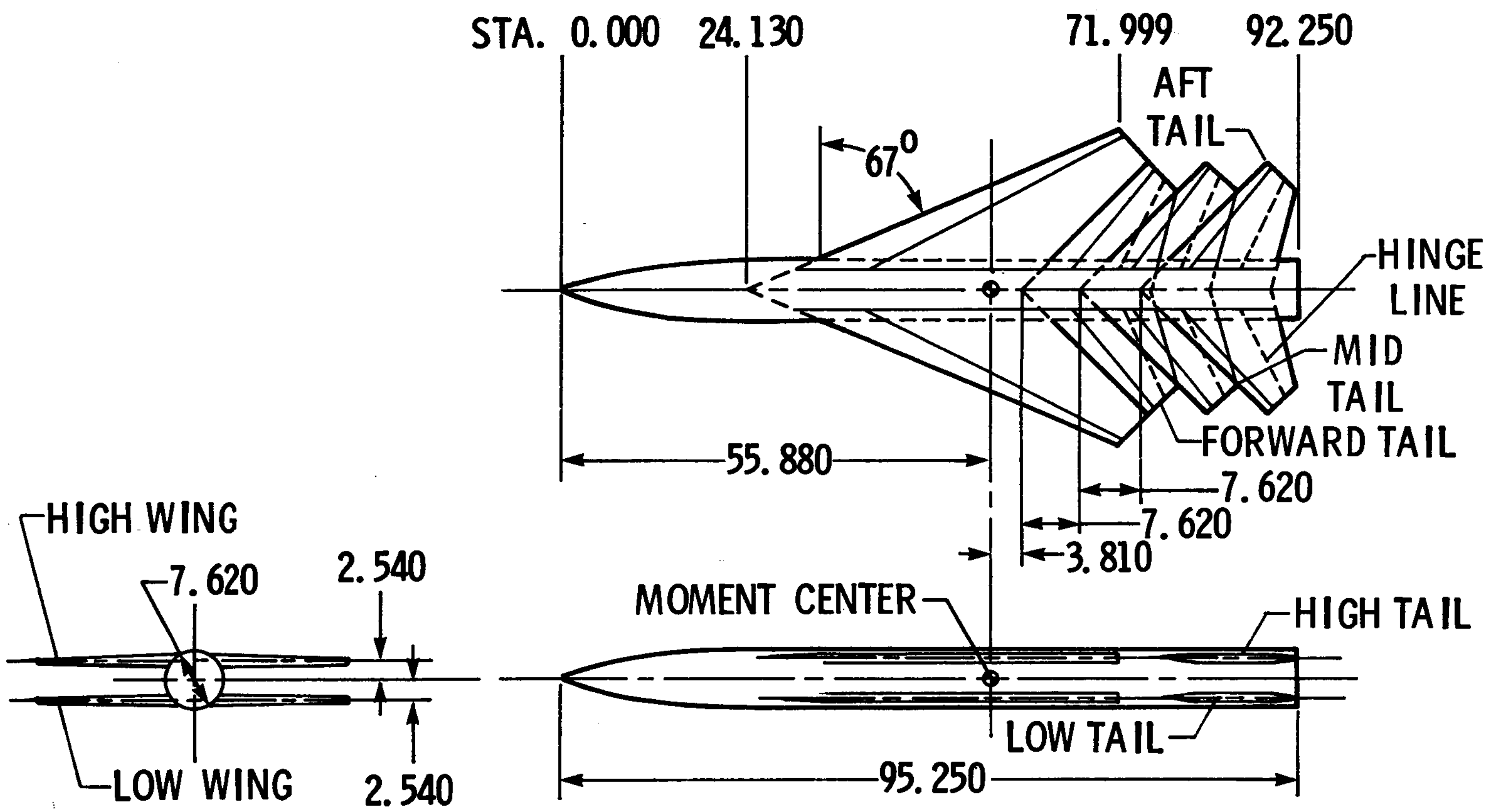
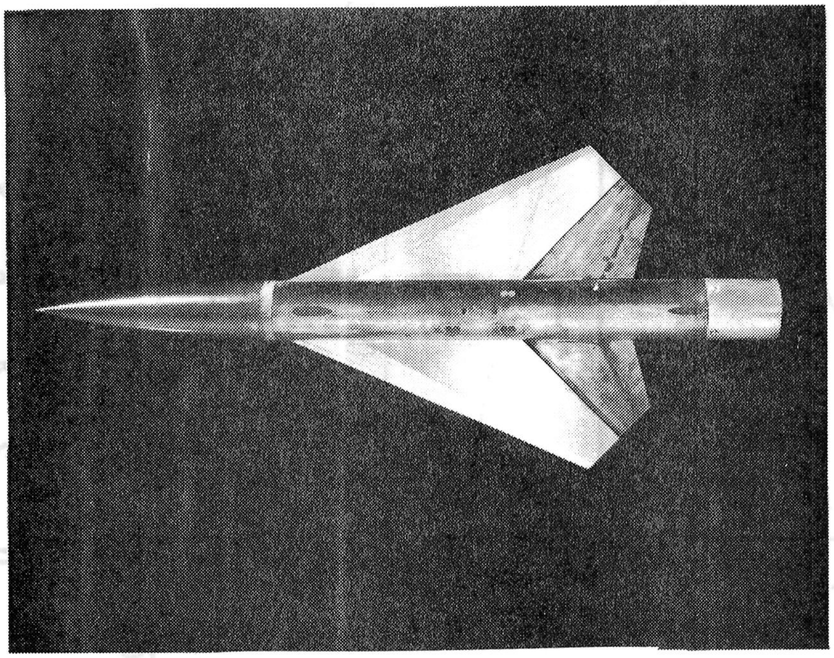
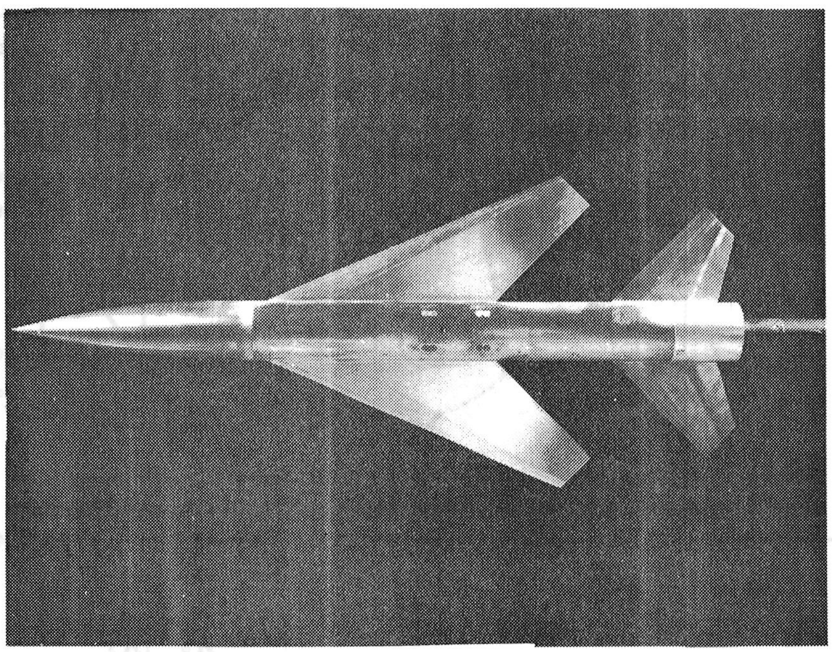


Figure 1.- Details of model. Linear dimensions in centimeters.



(a) Forward tail.



(b) Aft tail.

Figure 2. - Photographs of model.

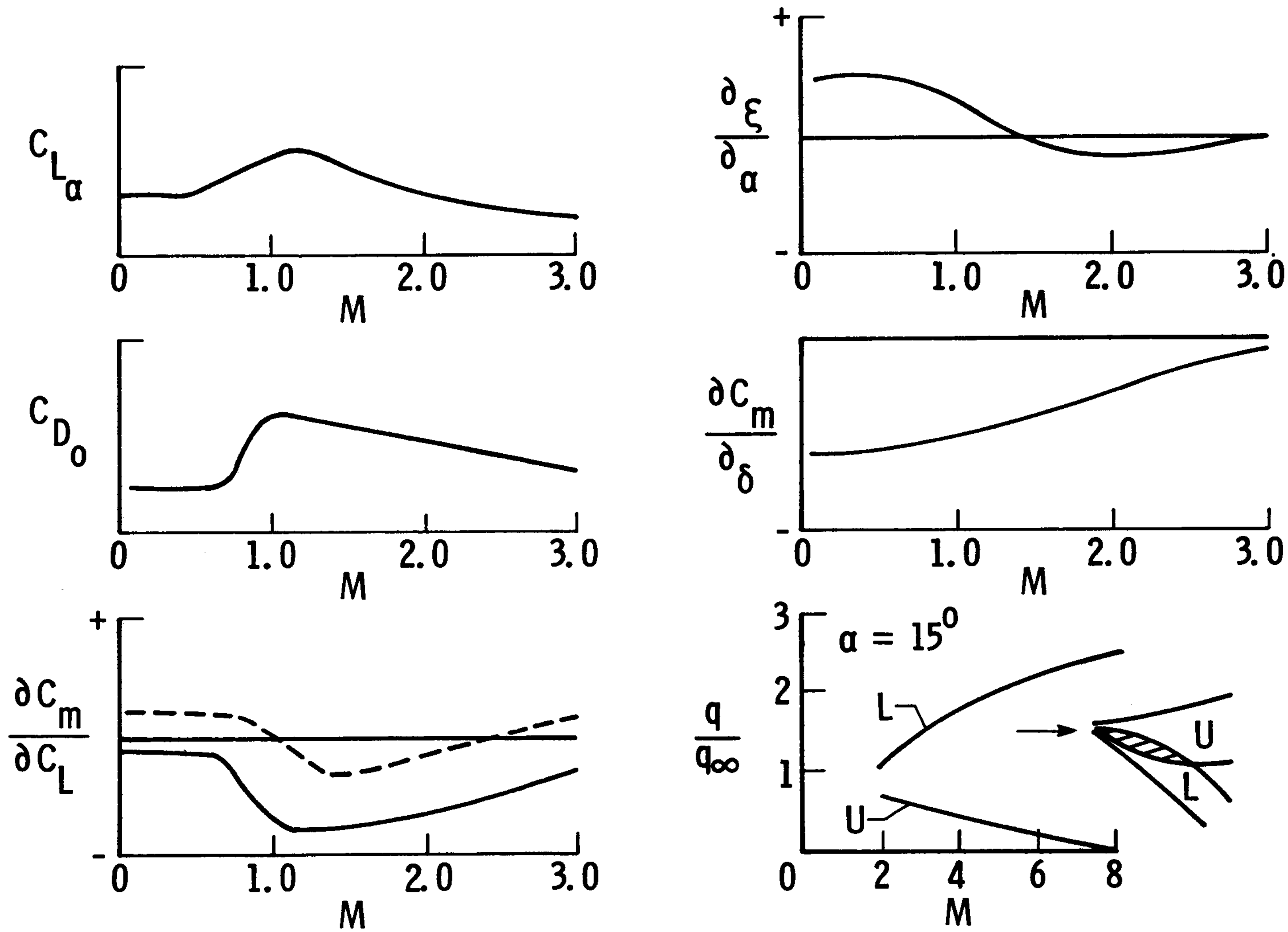
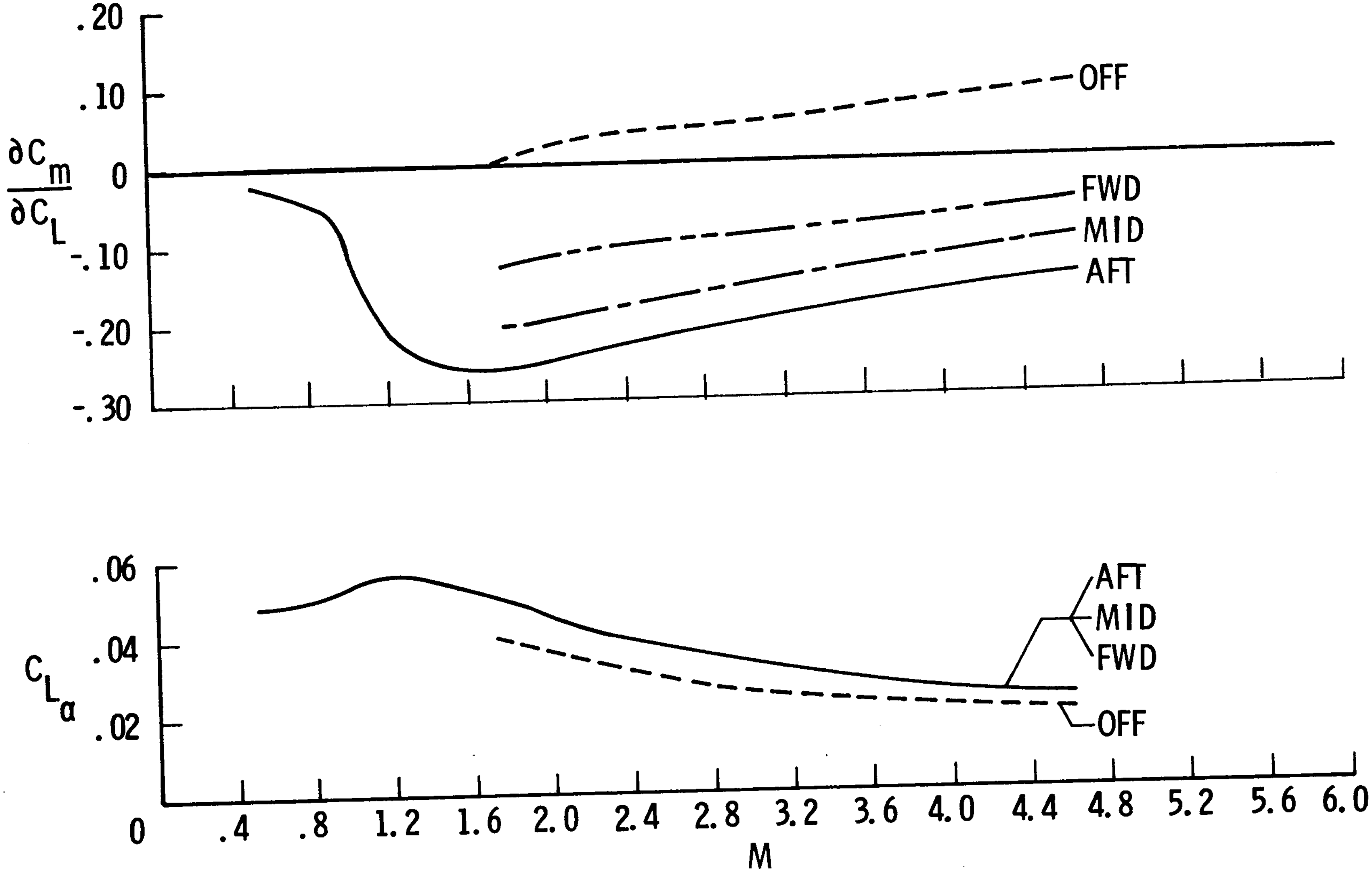
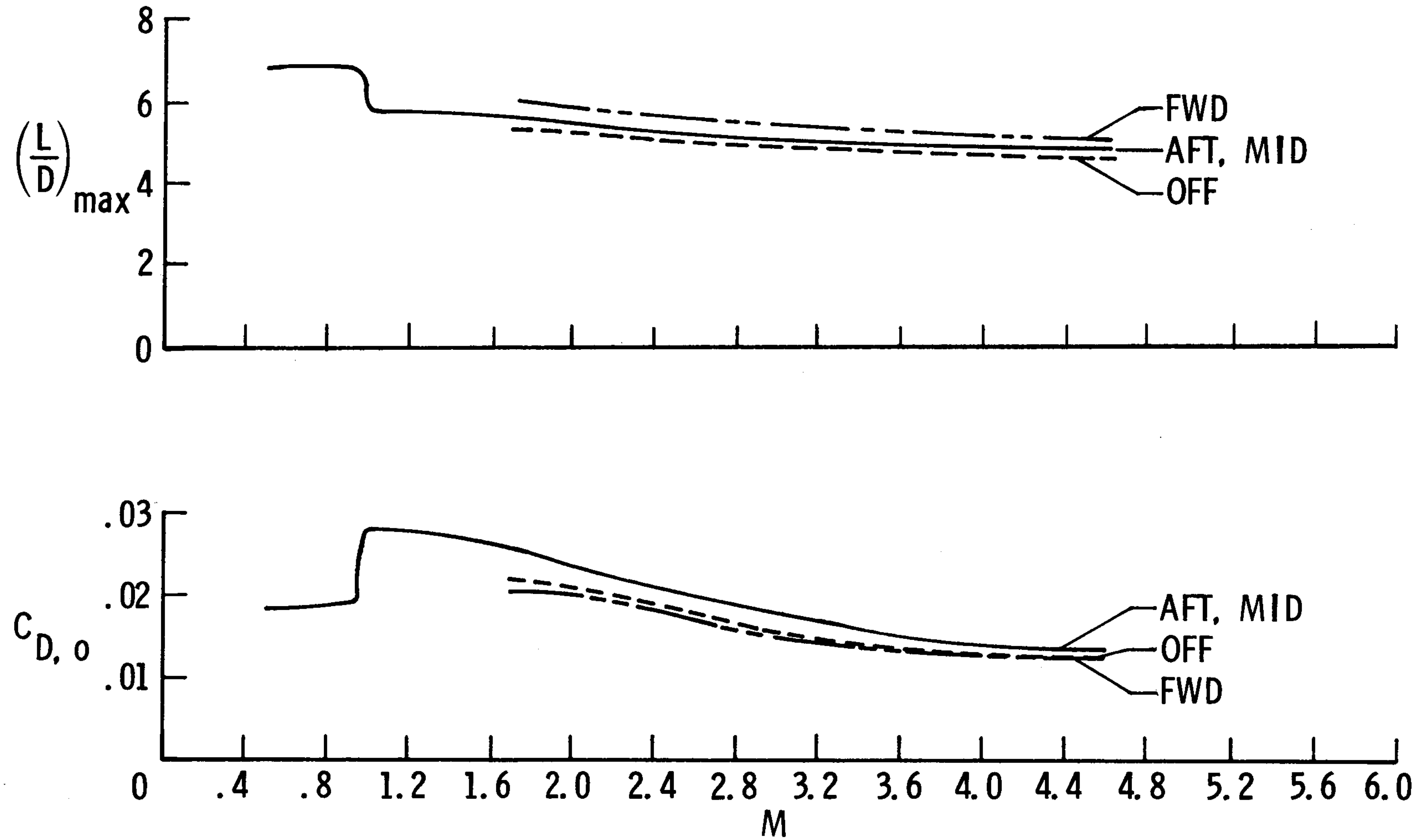


Figure 3.- Some Mach number effects.



(a) Variation of $\frac{\partial C_m}{\partial C_L}$ and of C_{L_α} with M.

Figure 4.- Longitudinal parameters. Centerline wing and tail.



(b) Variation of (L/D) max and of C_D, o with M.

Figure 4. - Concluded.

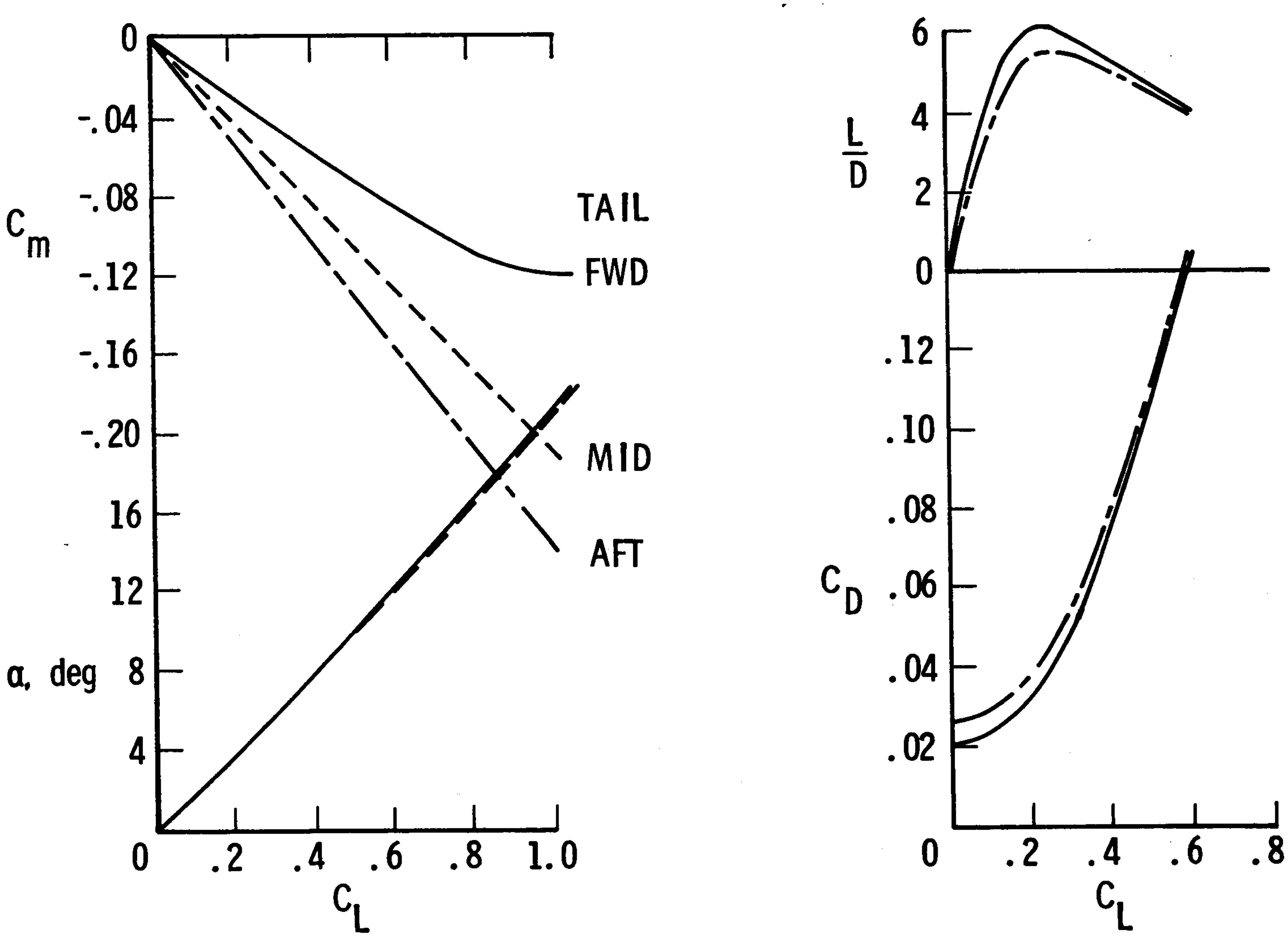


Figure 5 - Effect of tail length on longitudinal aerodynamics.
Centerline wing and tail, M = 1.70.

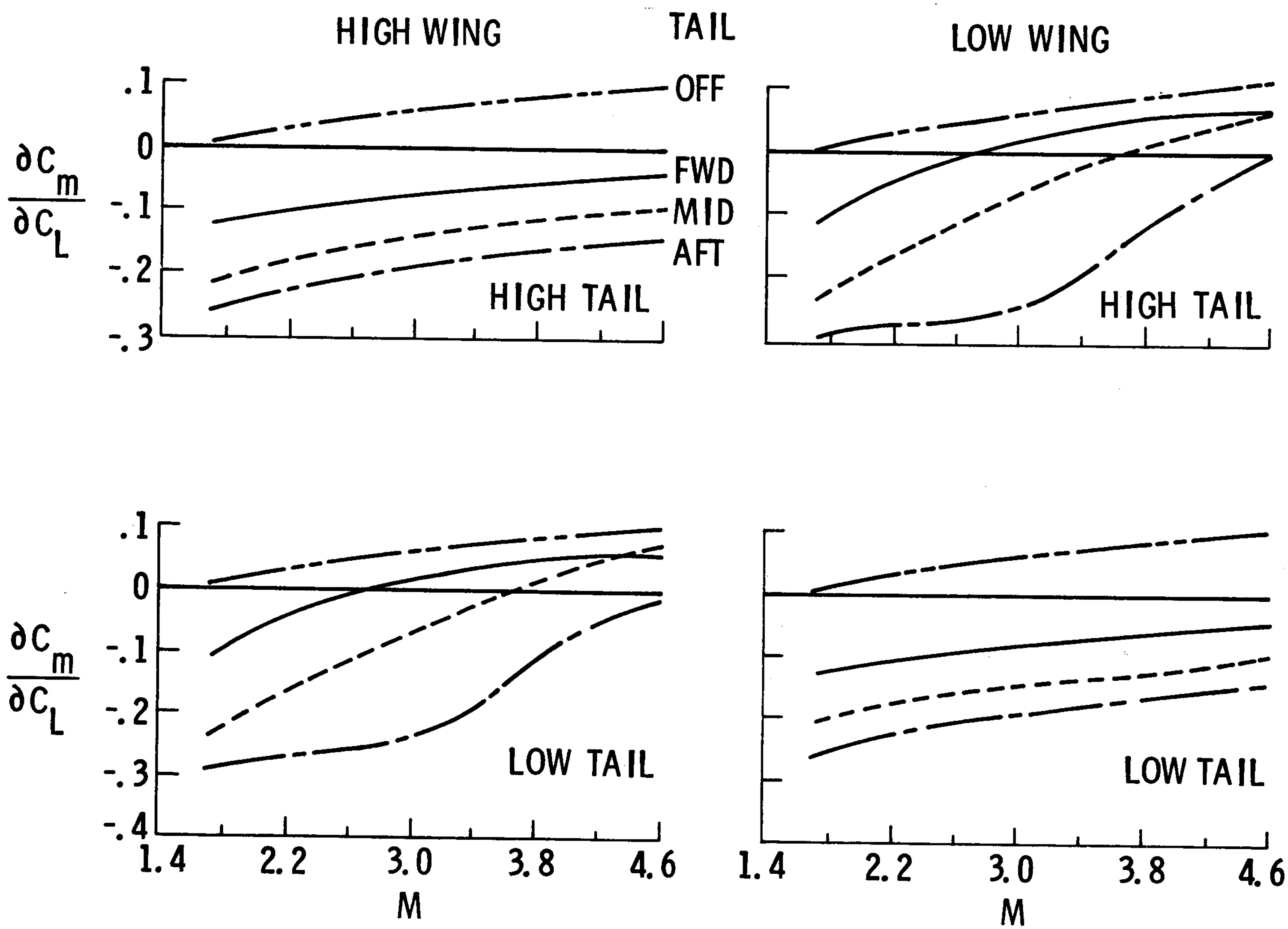


Figure 6.- Longitudinal stability for various wing and tail arrangements.

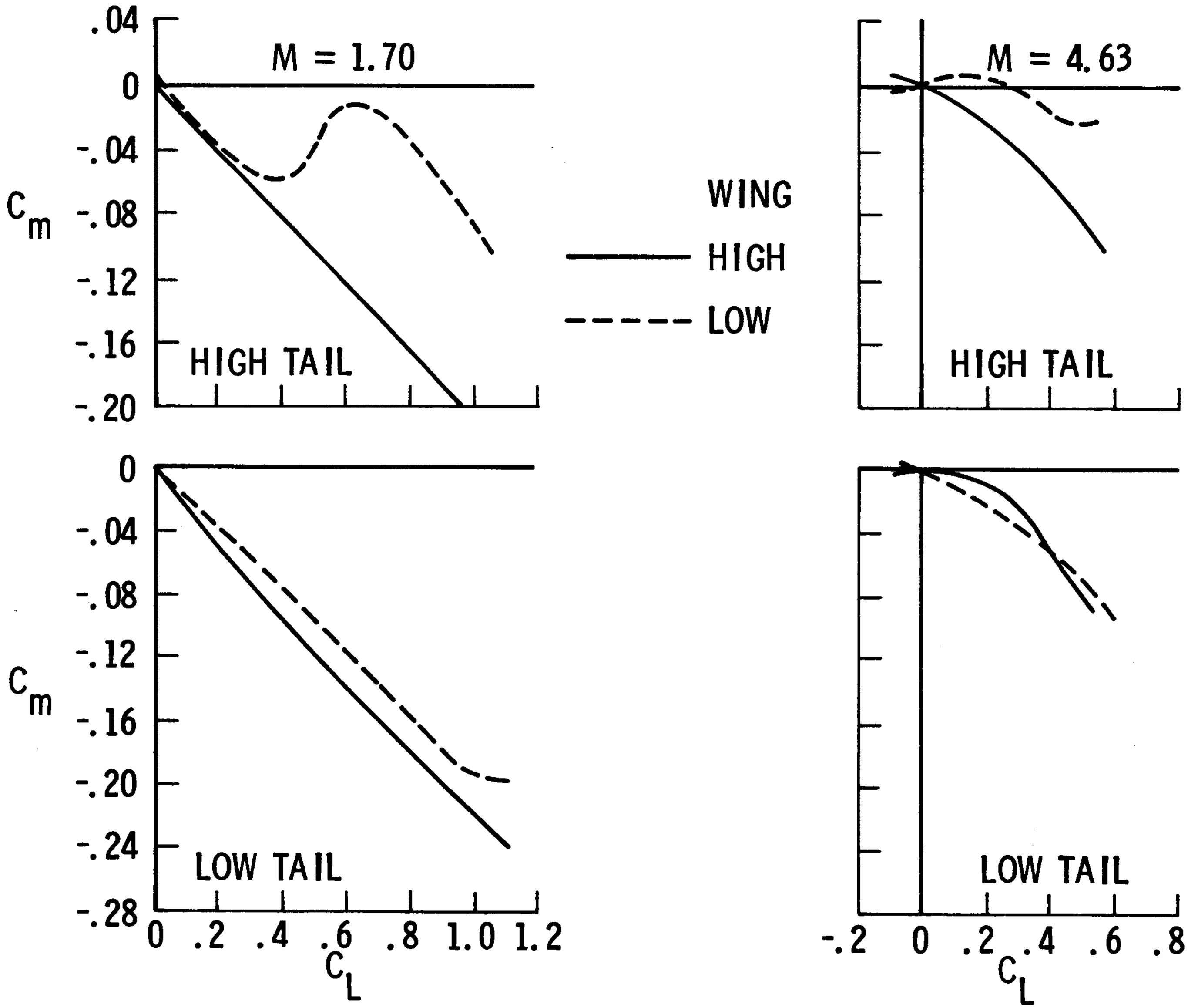


Figure 7 - Wing height effects on pitching moment characteristics.
Midtail length.

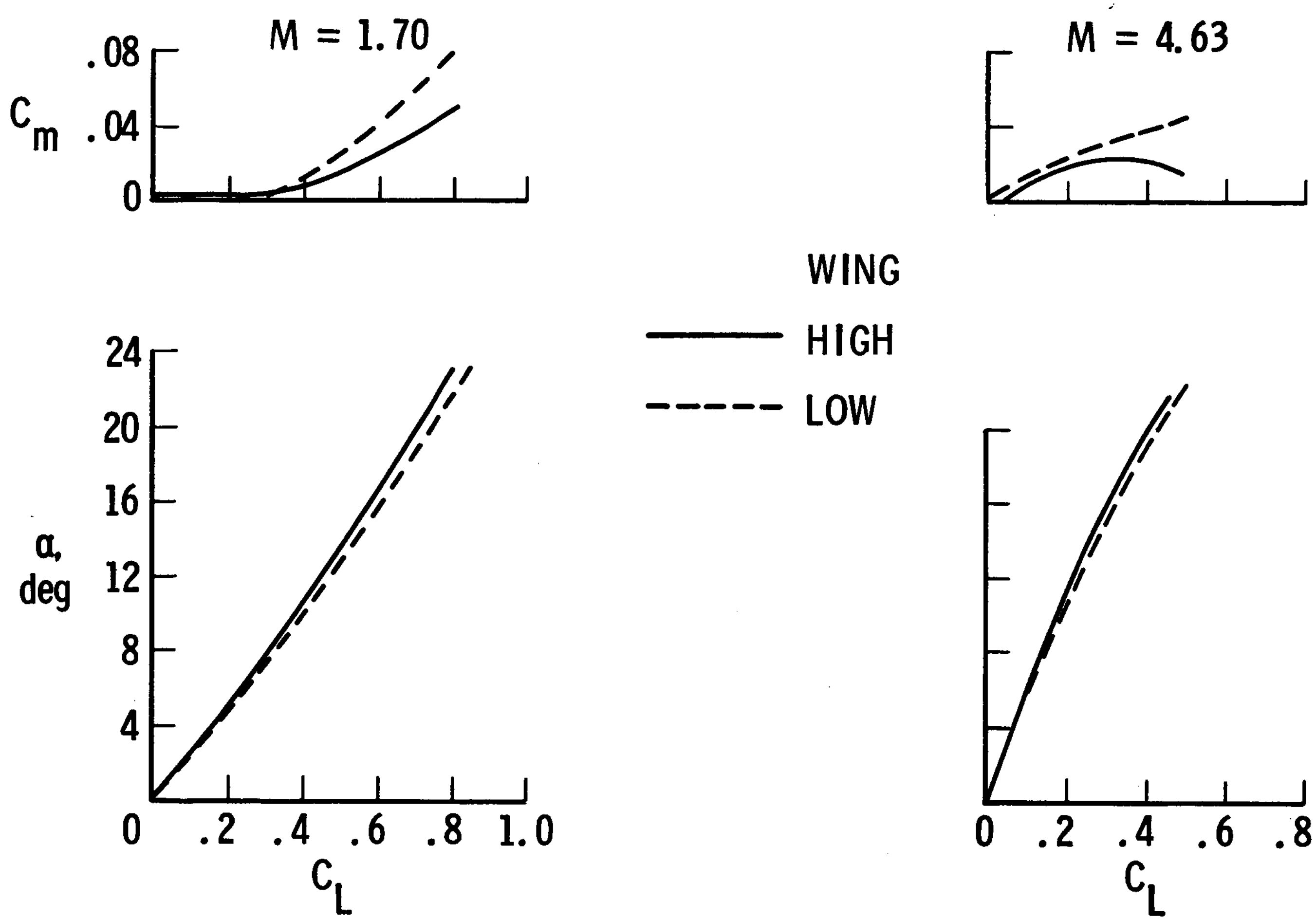


Figure 8.- Wing height effects on longitudinal aerodynamics. Tail off.

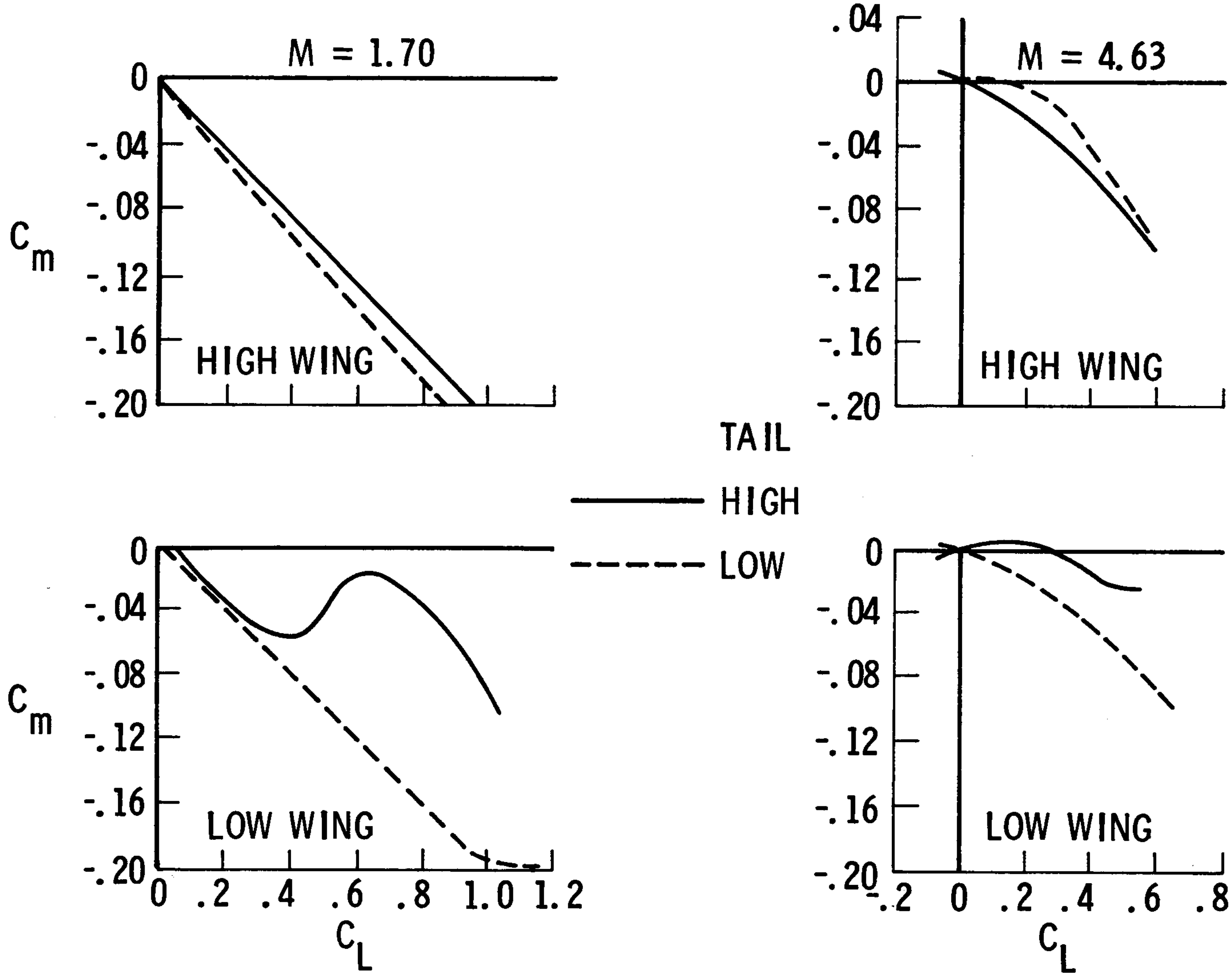


Figure 9 - Tail height effects on pitching moments characteristics.
Mid-tail length.

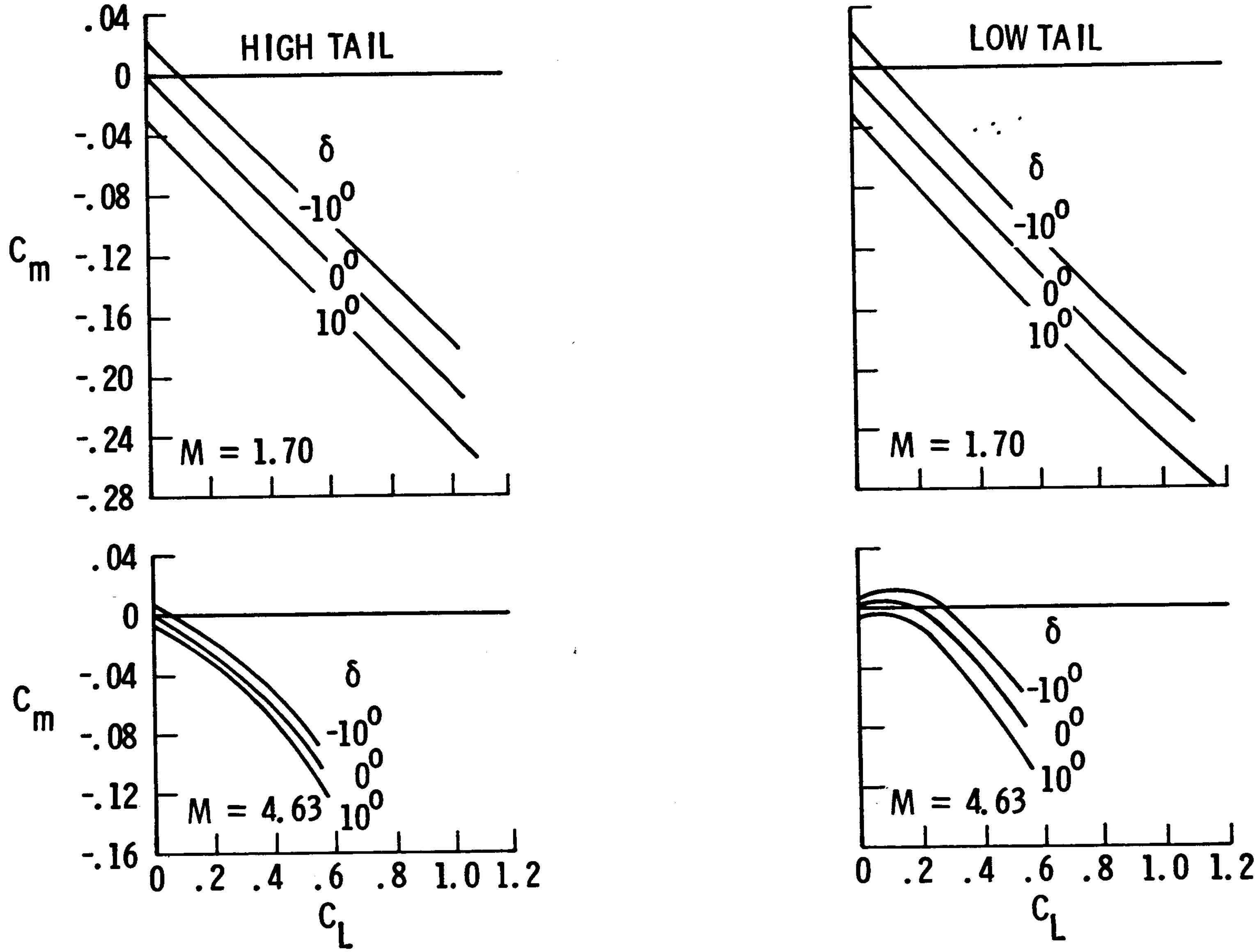


Figure 10.- Tail effectiveness. High wing, mid-tail length.

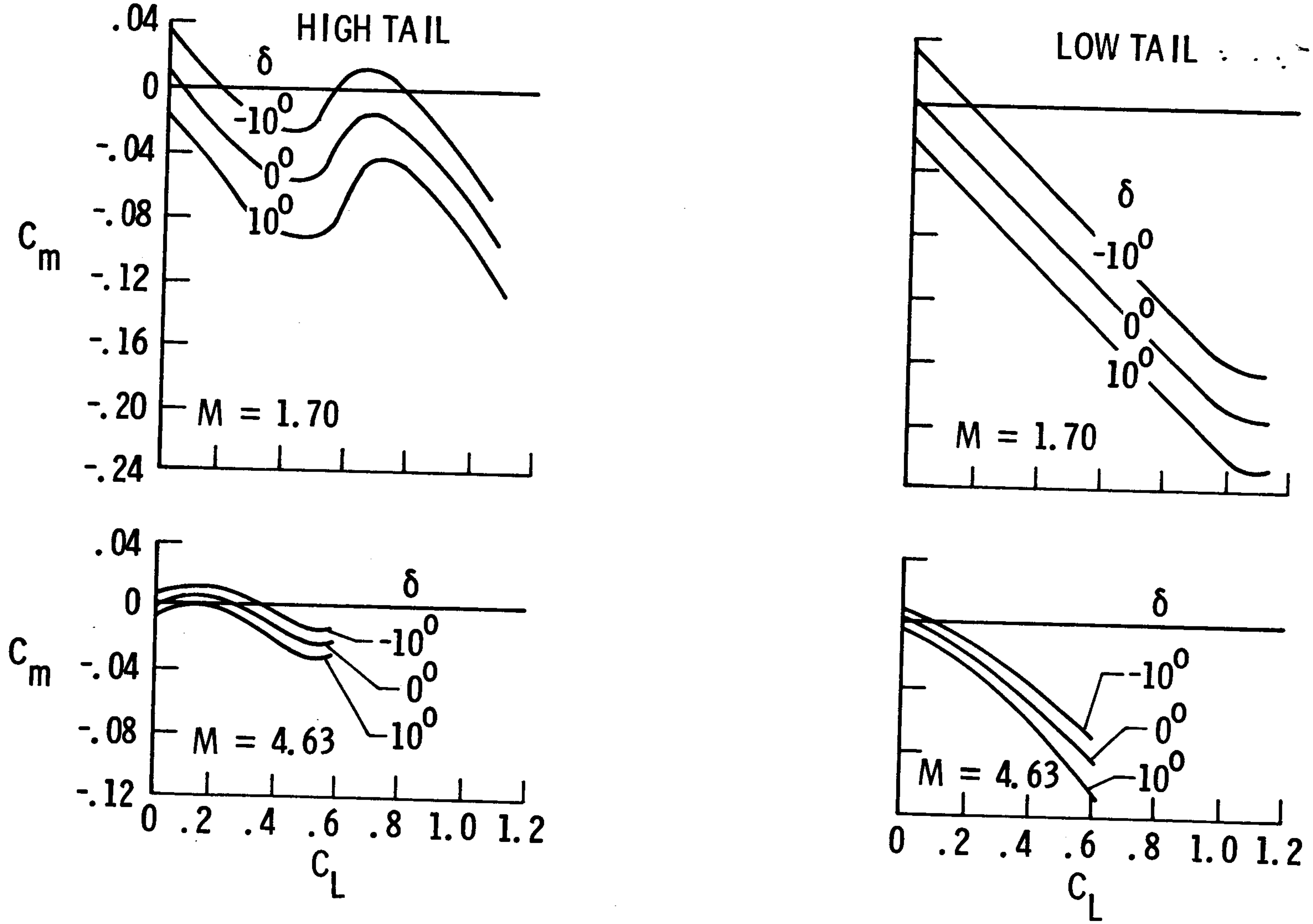


Figure 11.- Tail effectiveness. Low wing, mid-tail length.

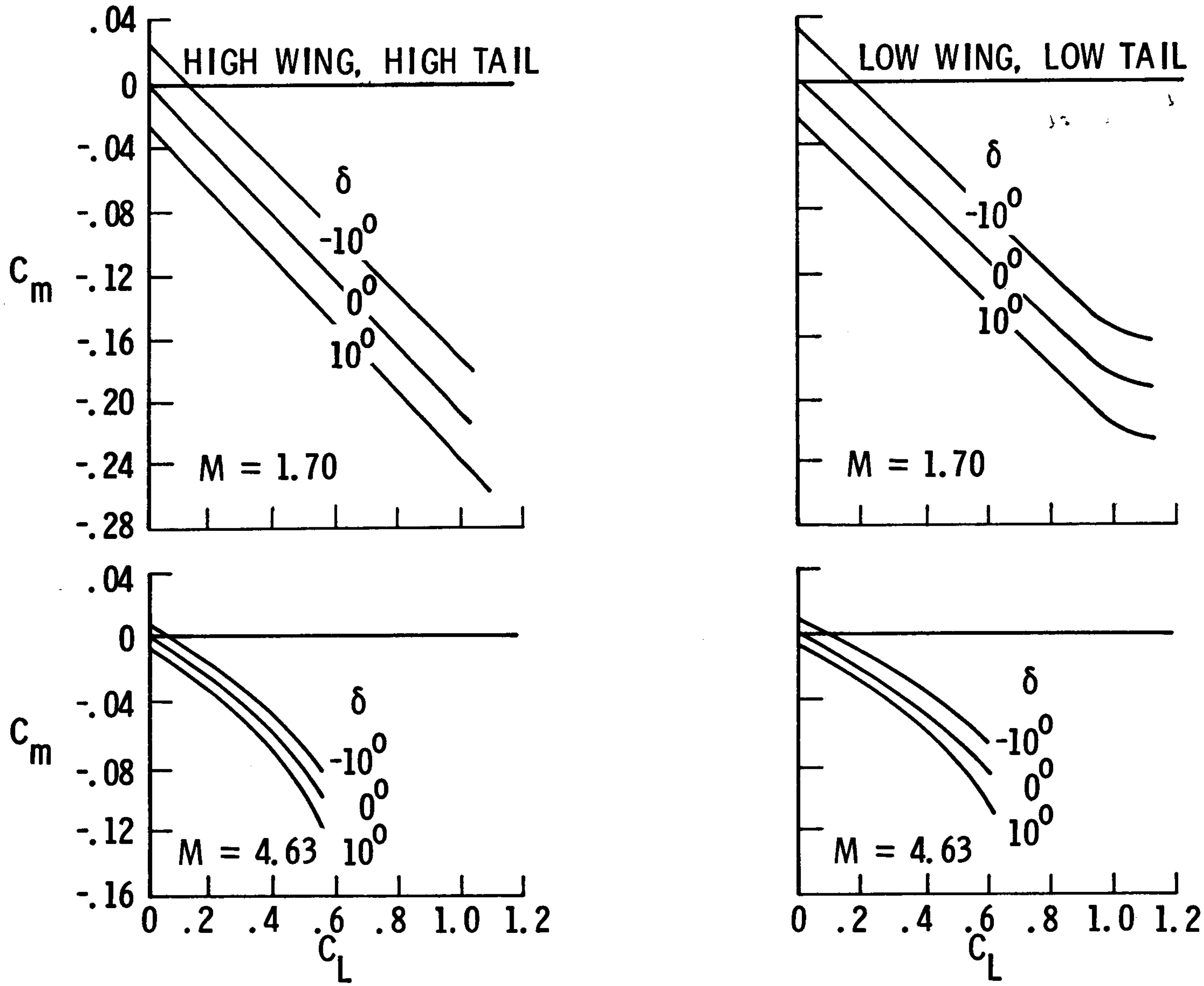


Figure 12.- Pitching moment characteristics with coplanar surfaces.
Mid-tail length.

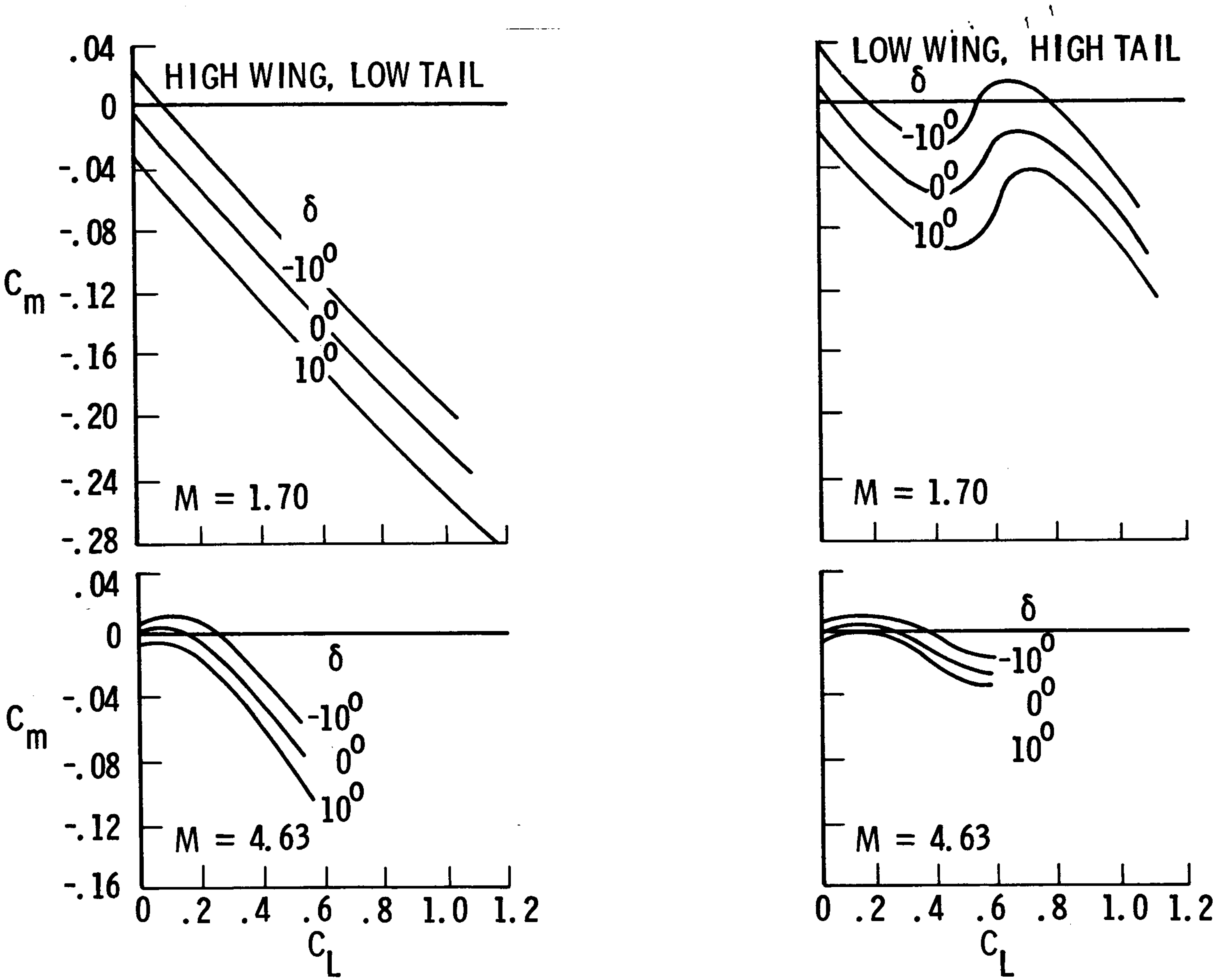


Figure 13. - Pitching moment characteristics with nonplanar surface. Mid-tail length.

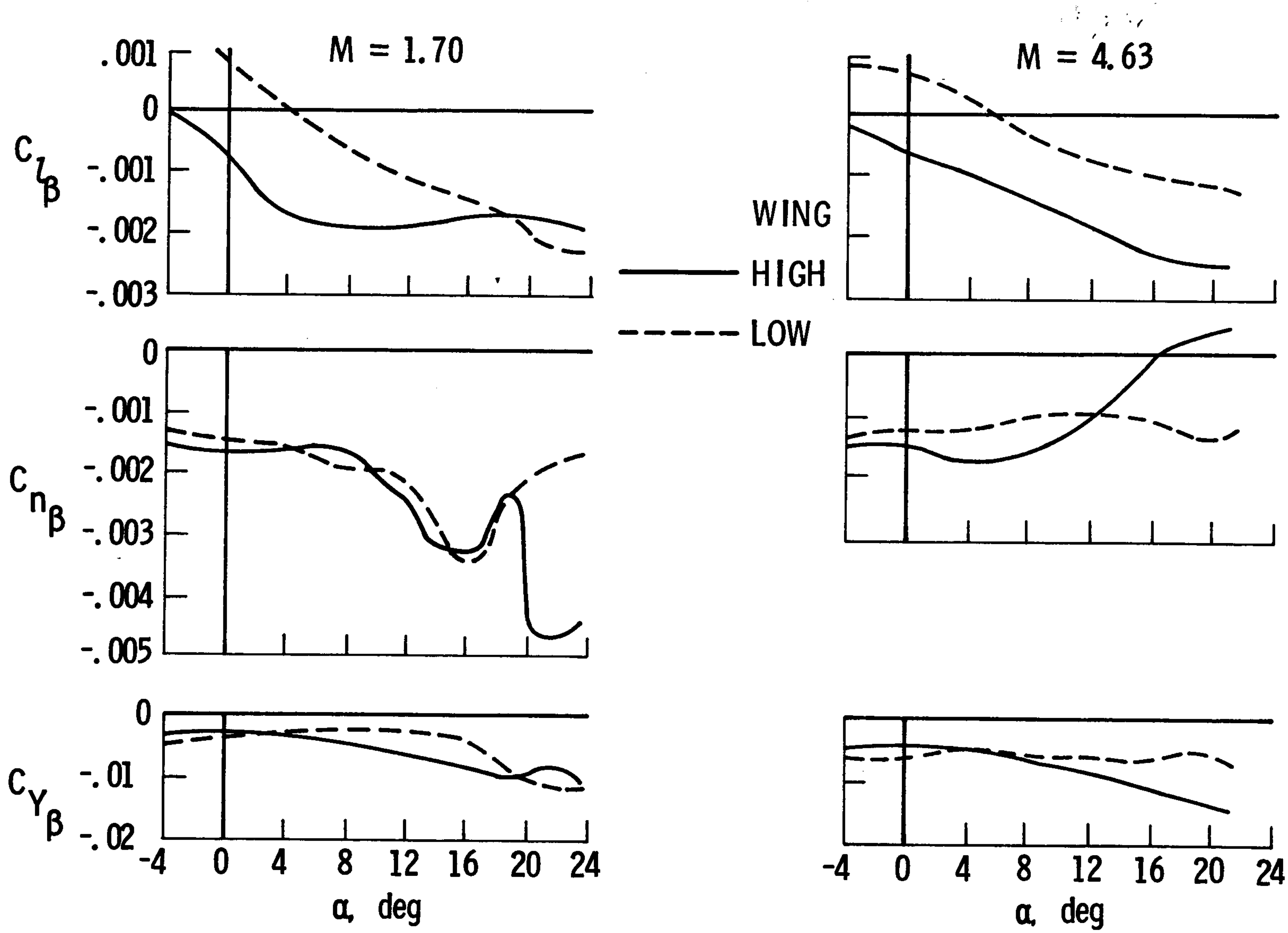


Figure 14.- Wing height effects on lateral characteristics. Tail off.

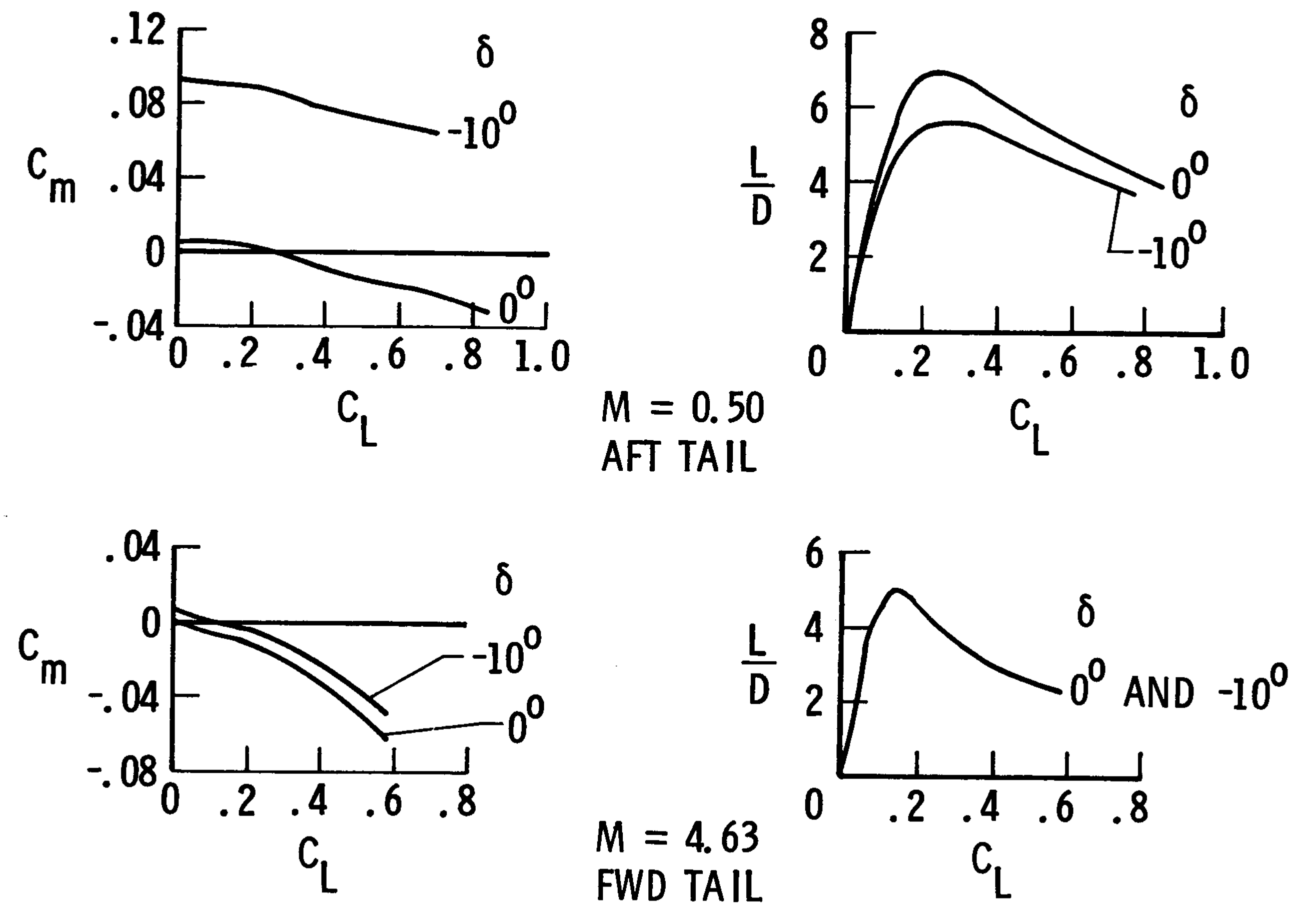


Figure 15.- Trim cruise characteristics. Centerline wing and tail.

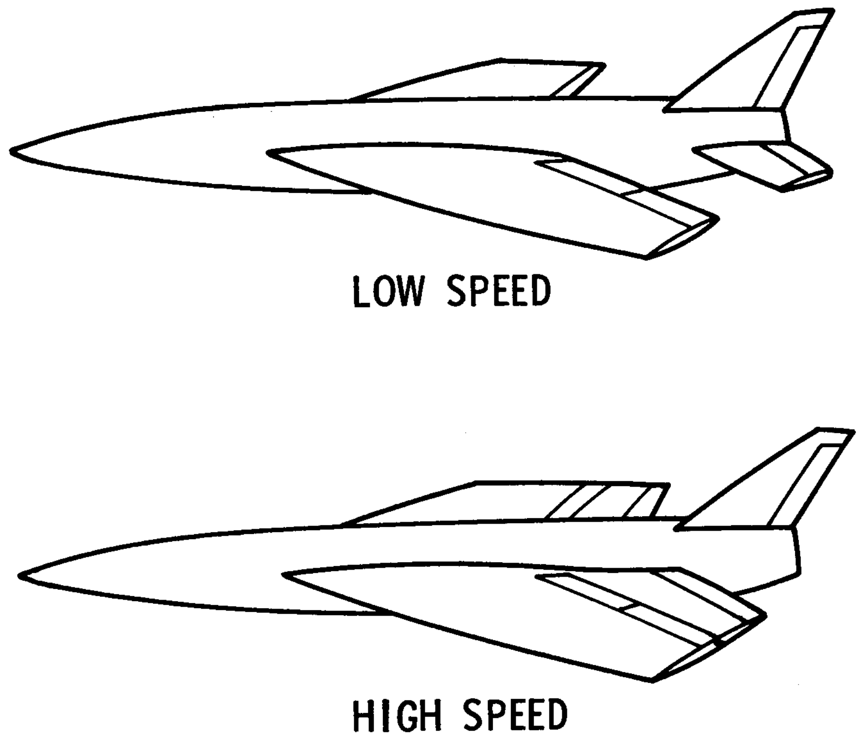


Figure 16.- Translating tail concept.

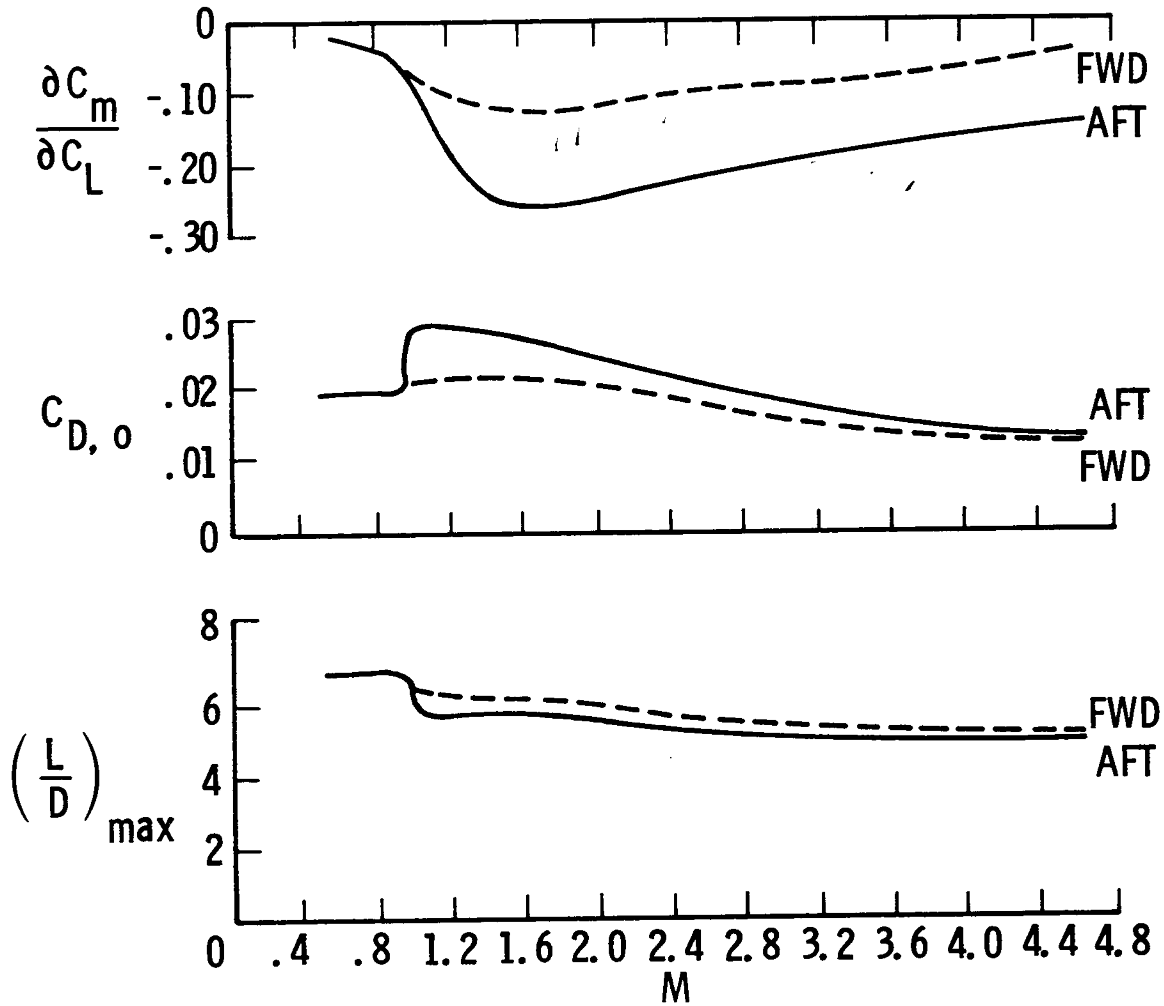


Figure 17. - Longitudinal characteristics for translating tail. Centerline wing and tail.

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16. Abstract

An experimental investigation was conducted to determine the effect of wing vertical position and horizontal-tail vertical and axial position on the static aerodynamic characteristics of a wing-body-horizontal-tail configuration. The configurations investigated included the wing in a high, mid, or low position on the body with the horizontal tail in each of these vertical positions as well as in three axial positions. The closest position of the horizontal tail to the wing essentially provided an all-wing configuration. In addition, tests were made for the three wing positions with the horizontal tail removed. The tests were made in three different wind tunnels to provide data for a Mach number range from 0.25 to 4.63. The purpose of the investigation was to illustrate the strong effects of interference flow fields as a function of geometry and flight attitude. The results indicate some arrangements that might lead to aerodynamic problems and others in which the interference flow fields might be favorably exploited. The results suggest that a coplanar concept with a translating horizontal tail could potentially minimize the aerodynamic changes with Mach number and provide more optimum performance over the Mach number range.

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